

Teaching Reform of Microgrid Course for Energy and Power Engineering Majors in the Context of New Power Systems

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Abstract: *The development of new power systems imposes new requirements on the cultivation of talents in energy and power engineering. Students are expected not only to master conventional energy conversion and utilization technologies, but also to develop a systemic understanding of issues such as multi-energy complementarity, source-storage coordination, and flexible operation. As a key carrier that integrates distributed energy resources, energy storage devices, and diversified loads, the microgrid serves as a pedagogical bridge connecting the core knowledge of energy and power disciplines with the application scenarios of new power systems. Given the knowledge background and academic characteristics of energy and power engineering students, this paper proposes a microgrid course teaching system structured around the principle of “virtual-real integration with AI assistance.” This system takes physical microgrid experimental platforms as the practical foundation, digital-twin-driven virtual simulation platforms as the space for extended exploration, and artificial intelligence tools as pedagogical aids, thereby forming a closed-loop teaching framework that covers the entire chain from theoretical cognition, through virtual simulation, to physical hands-on practice. The construction pathway of this teaching system is elaborated from four dimensions: course orientation and content optimization, innovation in teaching methodologies, experimental platform development, and reform of assessment systems, with verification drawn from practical explorations at selected universities. The study demonstrates that a virtual-real integrated teaching system tailored to the characteristics of energy and power engineering majors helps lower the cognitive threshold for students in interdisciplinary knowledge acquisition, alleviates the constraints imposed by physical experimental conditions on system-level practical training, and provides effective support for cultivating interdisciplinary talents equipped with a systemic perspective on multi-energy complementarity and robust engineering practice capabilities.*

Keywords: New power systems, Microgrid, Energy and power engineering majors, Virtual-real integrated teaching.

1. Introduction

Building new power systems constitutes a critical pathway toward achieving the nation’s carbon peaking and carbon neutrality goals. New power systems are characterized by high penetration of renewable energy, multi-energy complementarity and coordinated operation, and a high degree of intelligence. Their development depends not only on advancements in electrical engineering technologies, but is also closely intertwined with the discipline of energy and power engineering—efficient conversion of renewable energy, coupled utilization of multiple energy forms, and thermal management and safety assurance of energy storage systems all fall within the core knowledge domain of this field. Consequently, energy and power engineering programs are confronted with a pivotal pedagogical challenge: how to effectively bridge the fundamental knowledge of energy conversion with the engineering application scenarios of new power systems, so that students, while grasping the basic principles of energy conversion, can further develop a systemic understanding of energy system integration and operation.

The microgrid is precisely the ideal vehicle for realizing this pedagogical connection. A microgrid integrates distributed energy resources (such as photovoltaics, wind power, concentrating solar power, and micro gas turbines), energy storage devices (including electrochemical batteries, thermal storage, and hydrogen storage), and diversified loads into a controllable energy supply system, representing a typical paradigm of multi-energy complementarity and source-storage coordination. Within the microgrid, issues pertinent to

energy and power engineering—such as energy conversion efficiency, thermodynamic cycles, storage medium selection, and waste heat utilization—are deeply intertwined with concerns of power systems, including operational control, energy management, and security and stability, thereby forming a complete pedagogical chain of “energy production–conversion–storage–utilization.” Therefore, offering a microgrid course within energy and power engineering programs can help students establish effective connections between their specialized knowledge and system-level applications, laying the foundation for their adaptation to the talent demands of the energy industry under the new power systems framework. However, unlike electrical engineering majors, the curriculum for energy and power students is centered on engineering thermodynamics, fluid mechanics, heat transfer, and combustion, while the allocated class hours and depth of coverage in power system analysis, power electronics, and automatic control principles are relatively limited. This knowledge background presents three particular challenges for microgrid course instruction. First, the course content must achieve an effective transition from energy conversion principles to system integration applications within constrained contact hours, entailing a significant breadth of knowledge. Second, students possess a relatively weak foundation in electrical and electronic fundamentals, creating a cognitive threshold for understanding the control logic and power electronic conversion mechanisms involved in microgrids. Third, laboratory instruction must simultaneously compensate for the deficiency in theoretical grounding and cultivate systemic application capabilities, which imposes higher demands on teaching methods and platform conditions.

In recent years, the rapid advancement of virtual simulation technologies and artificial intelligence tools has offered new possibilities for addressing the aforementioned challenges. The virtual–real integrated teaching model combines the “authenticity” of physical experiments with the “scalability” of virtual simulation, making it particularly suitable for interdisciplinary courses that involve a broad knowledge span and high demands on experimental conditions. The integration of AI tools further enhances the intelligent assistance capabilities of virtual simulation platforms, enabling them to provide real-time feedback and guidance based on students’ operational behaviors, thereby lowering the learning threshold for students in unfamiliar knowledge domains. How to appropriately integrate these technological means into microgrid course instruction for energy and power engineering majors is the core issue addressed in this paper. This paper analyzes the pedagogical positioning and specific difficulties of microgrid courses for energy and power engineering majors in the context of new power systems, then elaborates on the basic architecture and operational logic of the virtual–real integrated teaching system. On this basis, it proposes a concrete construction scheme from four dimensions—course content, teaching methodology, experimental platform, and assessment approach—and further verifies the scheme through practical explorations at selected universities.

2. Pedagogical Positioning of Microgrid Courses for Energy and Power Engineering Majors in the Context of New Power Systems

2.1 Relevance of New Power System Development to Energy and Power Engineering

New power systems are predominantly based on renewable energy generation, and the efficient capture and conversion of renewable energy sources such as wind, solar, and biomass constitute the core research content of energy and power engineering—the aerodynamic design and optimization of wind turbines, the thermal characteristics of photovoltaic cells, and the concentration and thermal storage systems in concentrating solar power generation all fall within the knowledge domain of this discipline. Furthermore, new power systems emphasize multi-energy complementarity and integrated energy utilization; the combined cooling, heating, and power (CCHP) systems within microgrids involve typical energy and power engineering technologies such as thermodynamic cycles, waste heat recovery, and absorption refrigeration. Energy storage technology is a critical pillar of new power systems, and physical storage methods such as thermal storage, hydrogen storage, and compressed air energy storage are highly consistent with the thermodynamic and fluid mechanics foundations of energy and power engineering. Therefore, the energy and power engineering discipline plays an irreplaceable role in talent cultivation and technological innovation for new power systems. However, traditional teaching in energy and power engineering has primarily focused on energy conversion equipment and processes themselves—students are familiar with the working principles and performance optimization of individual devices such as boilers, steam turbines, internal combustion engines, and

compressors, but they lack training in the integrated operation and coordinated control of these devices within larger energy systems. What new power systems precisely demand is a “system-level perspective”—understanding the functional positioning, operational boundaries, and coordination modes of various energy conversion devices within the overall system. The microgrid course, serving as a pedagogical vehicle that embeds individual devices into system operation, precisely fills this gap.

2.2 Pedagogical Positioning of the Microgrid Course in Energy and Power Engineering Programs

Based on the above analysis, the teaching objectives of the microgrid course for energy and power engineering majors can be clearly defined as follows: building upon students’ fundamental knowledge of energy conversion principles, the course aims to further cultivate their “system-level” cognitive abilities—understanding the integration modes and operational characteristics of various distributed energy devices within the microgrid, grasping the coupling and conversion relationships among different energy forms, recognizing the principles of cascade energy utilization in combined cooling, heating, and power (CCHP) systems, and comprehending the energy dispatch logic based on load demands. In other words, the microgrid course designed for energy and power students should not be positioned as a “simplified version” of the microgrid course in electrical engineering, but rather as an “energy system integration version”—one that builds upon the energy conversion knowledge students have already acquired and extends upward to the level of integrated operation of multi-energy complementary systems. This course positioning is highly consistent with the core educational objective of energy and power engineering, namely “energy conversion and utilization,” and represents a concrete pedagogical practice through which the discipline responds to the talent demands of new power systems.

2.3 Analysis of the Characteristics of Students’ Knowledge Background

The curriculum of energy and power engineering undergraduates is grounded in thermal sciences and fluid sciences, with a solid foundation in mathematics and physics, yet with limited exposure to specialized knowledge in electrical engineering. Specifically, students have taken foundational courses in electrical engineering and electronics, gaining a basic understanding of fundamental circuit principles and basic electronic devices, but they lack systematic study of the topologies and operating principles of power-electronic converters. They have been exposed to fundamental content in automatic control principles, but are relatively unfamiliar with the operational control logic of power systems and the coordinated control strategies of microgrids. They understand the basic principles of energy conversion devices such as photovoltaic cells and fuel cells, yet have insufficient understanding of the dynamic characteristics and interface technologies of these devices when integrated into microgrids. This knowledge background dictates that the teaching of microgrid courses for energy and power engineering majors cannot simply transplant the teaching model from electrical engineering; rather, targeted

adjustments must be made in terms of course entry point design, knowledge presentation methods, and instructional support tools.

2.4 Major Difficulties in Teaching

Based on the above course positioning and students' knowledge background characteristics, microgrid course instruction for energy and power engineering majors faces three major difficulties. First, there is the tension between the broad knowledge span and limited contact hours. The course needs to proceed from the fundamental principles of energy conversion to the system architecture, operating modes, energy management, and control logic of microgrids, involving a long and wide knowledge chain. Accomplishing the pedagogical transition from "individual devices" to "system-level operation" within constrained class hours places high demands on the selection and organization of course content. Second, there is a gap between the abstract nature of theoretical instruction and students' cognitive foundations. Microgrid operation involves concepts such as power flow, frequency and voltage regulation, and grid-connected/islanded mode switching, which are unfamiliar territory for energy and power students. How to build a cognitive bridge to new concepts upon students' existing knowledge framework is a critical issue in instructional design. Third, laboratory instruction faces the dual task of both "supplementing foundational knowledge" and "constructing system-level understanding." Microgrid experiments for energy and power students should not only help them grasp fundamental principles of power electronic conversion and control (supplementing foundations), but also allow them to experience system-level operation processes of multi-energy integration (constructing system understanding). This imposes compound requirements on the functional design of experimental platforms and the hierarchical planning of experiment modules.

3. Construction of an AI-Assisted Virtual–Real Integrated Teaching System

To address the above difficulties, this paper proposes the construction of a microgrid course teaching system that integrates "virtual–real integration with AI assistance." The core idea of this system is to employ physical microgrid platforms to provide authentic engineering operational experience and intuitive physical cognition, to utilize digital-twin-driven virtual simulation platforms to expand spaces for knowledge bridging and breadth of scenario coverage, and to leverage AI tools to deliver personalized learning assistance and real-time feedback. The synergy of these three components lowers the cognitive threshold for students in interdisciplinary knowledge acquisition and improves teaching efficiency.

3.1 Course Content Optimization: Restructuring the Knowledge System for Energy and Power Engineering Majors

The primary task of course content reform is to restructure and optimize the knowledge system of the microgrid course in accordance with the knowledge background and educational objectives of energy and power engineering students.

In the introductory section of the course, the instruction should depart from the energy conversion principles that students have already learned, presenting the microgrid as a "system integration platform for various energy conversion technologies." By demonstrating the coordinated operation of photovoltaics, concentrating solar power, micro gas turbines, and energy storage technologies within the microgrid, students come to recognize that the microgrid is essentially a system-level application of energy conversion and utilization technologies, rather than a completely unfamiliar electrical system. In the section on distributed generation and energy integration, the teaching should highlight energy-interface characteristics while covering the working principles of various distributed generation sources. For photovoltaics, emphasis should be placed on the impact of output intermittency on system operation, and the role of thermal storage systems in concentrating solar power in smoothing output fluctuations should be introduced. For energy storage, the instruction should focus on comparing electrochemical storage and thermal storage in terms of response speed, energy density, and applicable scenarios, helping students develop the engineering mindset of selecting storage methods based on application requirements. The teaching should make full use of students' existing knowledge in thermodynamics and fluid mechanics—for instance, by drawing connections between concentrating solar power and thermodynamic cycles such as the Rankine cycle. When teaching grid-connected and islanded operating modes, the instruction should emphasize how energy supply–demand balance is achieved in each mode and how these modes affect the operating conditions of energy conversion devices. In the energy management segment, the teaching should highlight the dispatch decision-making process based on load demand, renewable generation output, and storage status, emphasizing the impact of dispatch strategies on overall system energy efficiency. The role of AI tools in this segment is to rapidly generate dispatch schemes based on meteorological and load data and to present them through visualization, enabling students to intuitively understand how dispatch strategies vary under different conditions.

3.2 Innovation in Teaching Methodology: A Three-Stage Progressive Model of "Foundation Supplementation – Virtual Simulation – Hands-on Practice"

Given the knowledge background of energy and power engineering students, a three-stage progressive teaching organization model of "foundation supplementation – virtual simulation – hands-on practice" is recommended.

The first stage is foundation supplementation and intensive theory instruction. Prior to the formal course content, combining intensive lectures with self-study to help students acquire essential knowledge, including basic types and functions of power electronic converters, fundamental concepts of common microgrid control modes, and basic power system terminology (the physical meanings of frequency, voltage, active power, and reactive power). The instruction should be concise and follow the principle of "sufficiency for practical use." An online learning platform provides micro-lecture videos and self-assessment quizzes; AI tools identify weak areas based on quiz results, push supplementary materials to students, and feedback the overall

class foundation status to the instructor.

The second stage is the virtual simulation phase, in which students conduct modeling, operational simulation, and scenario analysis of microgrids on a digital twin platform. This stage has two instructional objectives: first, to lower the comprehension threshold for abstract concepts through a visual simulation environment—for example, adjusting irradiance parameters to observe in real time the impact of photovoltaic output variations on system frequency and storage status; second, to allow system-level operational exercises and scenario exploration in a safe and controllable virtual environment, thereby compensating for the limited scenarios of physical platforms. The platform provides multi-level simulation scenarios, including standard operating conditions, typical weather conditions, and fault conditions. AI assistance permeates the entire process: when students encounter difficulties during operation, the system provides targeted hints; upon completion of each simulation, an experimental report draft (including key data extraction and trend analysis) is automatically generated, which students then refine and supplement.

The third stage is the hands-on practice phase, in which students perform designated operational tasks and verification experiments on the physical microgrid platform. Unlike simulations, physical operations must contend with practical issues such as sensor noise, device response delays, and environmental disturbances. Given that energy and power students have limited experience in electrical operations, this phase should be supported by clear laboratory manuals and adequate safety safeguards. Experimental tasks begin with simple device identification and status reading, then progressively advance to system-level operational procedures.

3.3 Experimental Platform Development: Emphasizing Visualization and Usability

For experimental platforms designed for energy and power engineering students, special attention should be paid to visualization and user-friendliness in functional design, so as to lower the cognitive threshold and reduce operational difficulty.

The physical microgrid platform should be configured under the principle of “safety, intuitiveness, and representativeness.” Core equipment includes photovoltaic simulators, lithium iron phosphate battery energy storage systems, bidirectional DC/DC converters, single-phase grid-connected converters, AC/DC adjustable loads, energy management controllers, and human-machine interfaces. Compared with platforms intended for electrical engineering majors, greater investment should be made in data display and status visualization, with sufficient display screens to present the system architecture diagram, energy flow directions, and operating status of each unit in real time, enabling students to grasp the overall system operation at a glance. The digital twin simulation platform serves as the core extended space of the virtual–real integrated teaching system. Built upon high-precision modeling tools, the platform constructs a full-digital mirror system of the microgrid, with the following functional features: First, visualized energy flow display — presenting the entire process of electricity generation, conversion, transmission,

and consumption within the microgrid through dynamic flow charts, thereby transforming the abstract concept of “energy balance” into intuitive graphics. Second, weather-to-output coupled simulation — students can adjust parameters such as irradiance, temperature, and wind speed to observe in real time the output variations of different energy forms, thereby understanding the sources and impacts of renewable energy uncertainty. Third, a multi-energy complementary scenario library — pre-configured with microgrid configurations and operational data for different scenarios such as industrial parks, islands, remote areas, and building complexes. By switching between scenarios and making comparisons, students can grasp the scenario-dependent nature of microgrid design. AI tools are embedded into the digital twin platform to form an “intelligent assistance layer,” providing data acquisition, behavior logging, and basic analysis during student operations. This includes recording operation sequence logs, issuing alerts for abnormal operations, and automatically aggregating key data and generating preliminary analytical charts upon experiment completion, all aimed at reducing the cognitive burden on students at the operational level.

3.4 Reform of the Assessment System: Emphasizing Process Tracking and Interdisciplinary Competence

Given the interdisciplinary learning characteristics of energy and power engineering students, the course assessment should place greater emphasis on tracking the learning process and evaluating the ability to integrate interdisciplinary knowledge.

In the design of assessment dimensions, the evaluation objectives can be divided into three levels: the basic level (weighted at 60%), which examines mastery of fundamental concepts and principles; the interdisciplinary application level (weighted at 20%), which assesses students’ ability to apply energy and power engineering knowledge to analyze and solve microgrid system problems—such as energy efficiency analysis of multi-energy complementary systems and techno-economic comparisons of energy storage options—thereby reflecting the unique value of the microgrid course for the energy and power discipline; and the simulation and practice level (weighted at 20%), which evaluates students’ operational and analytical capabilities in virtual simulation and physical experiments. In terms of assessment methods, AI tools assist in the collection and preliminary analysis of process data. The digital twin platform automatically logs simulation operation records, and AI compiles them into a “brief summary of the simulation learning process” for instructor reference. The online learning platform records video viewing progress, self-assessment scores, and discussion participation, with AI automatically generating an overview of learning engagement. The role of AI in the assessment process is that of a data-collection and preliminary-organization tool; all assessment judgments and grade determinations are made by the instructor.

4. Relevant Practical Explorations

The above reform ideas are consistent with the teaching exploration directions undertaken by several universities in energy and power engineering and related disciplines in recent years. Representative cases are presented below.

4.1 Shanghai University of Electric Power: Virtual–Real Integrated Teaching for Microgrids Oriented toward Application-Oriented Talent Cultivation

Shanghai University of Electric Power has developed a “Virtual Simulation Experiment for Energy Conversion, Collection, and EMS Management Systems on a Green Campus.” The experiment adopts a progressive content design of “foundation–comprehensive–exploratory” and, through three-dimensional modeling, fully reproduces the campus energy system in which multiple units—including photovoltaics, wind power, energy storage, and loads—interact and operate.

4.2 Nanjing University of Science and Technology: Modular Design of Virtual Simulation Experiments for Microgrids

Nanjing University of Science and Technology has developed a “Virtual Simulation Experiment for Microgrid Operation and Fault Analysis” course. Based on an actual microgrid prototype, the course constructs a virtual system through 3D simulation, comprising five modules—microgrid cognition, operational procedures, hazards of unintentional islanding operation, protection setting and analysis, and fault analysis and handling—covering 18 operational steps across three levels: “fundamental principles, basic skills, and exploratory practice.” To date, this experiment has been participated in by 1,226 students, with a completion rate of 96.49%. Its modular progressive design is particularly suitable for cross-disciplinary students.

4.3 University of Pavia, Italy: An Off-Grid Microgrid Laboratory Platform for Educational Purposes

University of Pavia has developed a fully off-grid laboratory-scale microgrid integrating photovoltaic generation, wind power, and battery energy storage. Designed with a modular architecture and equipped with adjustable loads to simulate diverse operating conditions, the platform offers students direct hands-on experience in microgrid operation and energy management under islanded conditions. Its pedagogical philosophy emphasizes bridging the gap between theoretical knowledge and practical application, providing an interactive experimental environment where undergraduate and graduate students can explore, test, and validate various operational scenarios. This case demonstrates how a well-designed physical platform, even on a modest scale, can effectively support experiential learning in microgrid education for energy-related disciplines.

The common features of the above cases are as follows: they emphasize the use of visualization to lower the comprehension threshold for interdisciplinary knowledge, expand the scope of practical scenarios through virtual simulation, and accommodate the learning needs of students with diverse knowledge backgrounds through modular design. These experiences provide direct and valuable reference for the construction of microgrid courses tailored to energy and power engineering majors.

5. Conclusion

The development of new power systems has imposed new requirements on the cultivation of talents in energy and power engineering—extending from a past focus on energy conversion equipment and processes themselves to an in-depth understanding of the integrated operation of multi-energy complementary systems. The microgrid course, serving as a pedagogical bridge connecting the core knowledge of energy and power disciplines with the application scenarios of new power systems, has become increasingly valuable in the talent cultivation system of this field.

Focusing on the knowledge background characteristics of energy and power engineering students, this paper has analyzed the difficulties faced by microgrid course instruction—including the broad knowledge span, high cognitive threshold, and special demands on experimental conditions—and has proposed a teaching system construction scheme based on “virtual–real integration with AI assistance.” This scheme employs physical platforms to ensure fundamental operational experience, digital twin simulation to expand cognitive scenarios, and AI tools to lower the threshold for interdisciplinary learning. The synergy of these three components supports the three-stage progressive teaching process of foundation supplementation, virtual simulation, and hands-on practice.

The construction of microgrid courses for energy and power engineering students is an exploratory teaching reform practice that requires continuous accumulation of experience and optimization of schemes through practical implementation. With the continued maturation of digital twin technologies and the ongoing evolution of AI-assisted teaching tools, the virtual–real integrated teaching model will provide even stronger support for the instruction of interdisciplinary courses in energy and power engineering. Universities of different levels and with distinct educational characteristics should, based on their own disciplinary directions and resource conditions, explore pathways for microgrid course development that suit the characteristics of their own students, so as to cultivate and deliver more interdisciplinary talents equipped with systems thinking and cross-disciplinary integration capabilities for the construction of new power systems and the green and low-carbon transition of the energy industry.

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